

# The Assessment of Water Environmental Quality Based on Extension Method

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## Abstract

This paper is concerned with the problems that extension method is used in water quality assessment. At first, the way is recommended to build the matter-element model of comprehensive assessment on water environmental quality. Then, six commonly measured water quality variables are selected as evaluation parameters, including dissolved oxygen, chemical oxygen demand, permanganate index, nitrite nitrogen, nitrate nitrogen and total phosphorus. The model was utilized to evaluate water quality of the water intake of the Yellow River in Zhengzhou, China. The evaluated results obtained from the matter-element model was the same as the fuzzy comprehensive assessment. Through the case study, this paper also has analyzed the characteristics of the matter-element model, in addition, the sensitivity analysis about dissolved oxygen parameter has carried out and showed that dissolved oxygen was not sensitive parameter in this case.

## Keywords

*Water Environmental Quality; Matter-Element Model; Comprehensive Assessment; Dependent Degree; Sensitivity Analysis*

## Introduction

Assessment of water environmental quality can be defined as the status classification of water environmental quality. There are a lot of methods of water environmental quality assessment to be applied in practice, for example, pollution index [Peng and Zhang, 2005], Horton's index [Horton, 1965], Brown's index [Brown, et al., 1970], Nemerow's index [Nemerow, 1974], Ross's index [Ross, et al., 1977], fuzzy comprehensive assessment based on the fuzzy set [Pan, et al., 2002], B-P model based on artificial neural network [Lou and Wang, 2003], methods based on genetic algorithm [Jin, et al., 2004], and other water quality indices [Bharti and Katyal, 2011]. Recently, new theories presented by Chinese scholars have been widely used to evaluate water environmental quality, which are grey relational analysis [Zhou, 2007], grey cluster [Zhou, et al., 2007] and grey situation decision

[Liu and Zhong, 2005] based on the grey system theory [Deng, 2002], connect number [Gao, et al., 2009] [Gao, 2010] based on set pair analysis [Zhao, 2000], matter-element analysis [Gao and Lu, 2010] [Gao, et al., 2011] based on extencis [Cai, 1999]. In this paper, it is introduced that matter-element model is used to evaluate water environmental quality, and characteristics of the model are also investigated.

## Matter-Element Model

Extencis established in 1983 by professor Wen Cai, whose research object is contradictory problems in the world, studies the law and methods dealing with contradictory problems. That is, extencis is such a science that uses formal model to research the extension possibility of things, the rules and methods of innovation, and applies all of them to solve contradictory problems [Cai, et al, 2003]. In extencis, matter-element is taken as basic-element, then its model is established, and matter-element extension (things change) is regarded as the basis, matter-element transformation method is applied to change contradictory problems for compatibility problems, thus solving the problems. The following is the mathematical model of matter-element analysis and evaluation, which is matter-element model of comprehensive assessment.

## Matter-Element and Matter-Element Martrix

Given the name of thing  $N$ , it's about characteristic of  $c$  value for  $v$ , the ordered three element group  $R=(N, c, v)$  may describe things basic element, defined as the matter-element. The name of thing, characteristic, and value are referred to as the three factors of a thing.

One thing has usually more characteristics. Given the name of thing  $N$ , having characteristic  $c_i (i=1, 2, \dots, n)$ , and  $c_i$  value for  $v_i (i=1, 2, \dots, n)$ , so  $n$  dimensional matter-element is expressed as bellow:

$$R = \begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}$$

Where  $R$  is the matter-element matrix, briefly written as  $R=(N, C, V)$ .

### The Martrix of Classic Domain

Classic domain of comprehensive assessment is given bellow:

$$R_{0j} = \begin{bmatrix} N_{0j} & c_1 & x_{0j1} \\ & c_2 & x_{0j2} \\ & \vdots & \vdots \\ & c_n & x_{0jn} \end{bmatrix} = \begin{bmatrix} N_{0j} & c_1 & \langle a_{0j1}, b_{0j1} \rangle \\ & c_2 & \langle a_{0j2}, b_{0j2} \rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{0jn}, b_{0jn} \rangle \end{bmatrix}$$

Where  $N_{0j}$  is classification  $j$  divided into the evaluation,  $c_i$  is characteristic  $i$  of  $N_{0j}$ ,  $x_{0ji}$  is range of  $c_i$  about  $N_{0j}$ .  $a_{0ji}$ ,  $b_{0ji}$  are lower and upper limit of  $x_{0ji}$ . That is, classic domain is the value range of  $c_i$  in the classification  $N_{0j}$ .

### The Martrix of Whole Domain

The whole domain of comprehensive assessment is given bellow:

$$R_p = \begin{bmatrix} P & c_1 & x_{p1} \\ & c_2 & x_{p2} \\ & \vdots & \vdots \\ & c_n & x_{pn} \end{bmatrix} = \begin{bmatrix} P & c_1 & \langle a_{p1}, b_{p1} \rangle \\ & c_2 & \langle a_{p2}, b_{p2} \rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{pn}, b_{pn} \rangle \end{bmatrix}$$

Where  $P$  is the all classifications,  $x_{pi}$  is value range of  $c_i$  about  $P$ .  $a_{pi}$ ,  $b_{pi}$  are lower and upper limit of  $x_{pi}$ , respectively. That is, the whole domain is the value range of  $c_i$  in all of the classifications.

### Matter-Element for Evaluating

$$R_0 = \begin{bmatrix} P_0 & c_1 & x_1 \\ & c_2 & x_2 \\ & \vdots & \vdots \\ & c_n & x_n \end{bmatrix}$$

Where  $R_0$  is matter-element to evaluate,  $P_0$  is name of object for evaluation,  $x_i$  is value of  $c_i$ .

### Dependent Degree

#### 1) The Distance from a Point to Limited Interval

In extencis, the distance  $\rho(x_i, x_{0ji})$  from point  $x_i$  to limited interval  $x_{0ji}=[a_{0ji}, b_{0ji}]$  is defined as:

$$\rho(x_i, x_{0ji}) = \begin{cases} x_i - \frac{a_{0ji} + b_{0ji}}{2} & x_i \geq \frac{a_{0ji} + b_{0ji}}{2} \\ \frac{a_{0ji} + b_{0ji}}{2} - x_i & x_i < \frac{a_{0ji} + b_{0ji}}{2} \end{cases}$$

#### 2) Dependent Function

The formula of dependent function  $K_j(x_i)$  is given

below:

$$K_j(x_i) = \begin{cases} -\frac{\rho(x_i, x_{0ji})}{|x_{0ji}|} & x_i \in x_{0ji} \\ \frac{\rho(x_i, x_{p0j}) - \rho(x_i, x_{0ji})}{\rho(x_i, x_{p0j}) - \rho(x_i, x_{0ji})} & x_i \notin x_{0ji} \end{cases}$$

Where  $\rho(x_i, x_{p0j})$  is the distance of point  $x_i$  to limited interval  $x_{p0j}=[a_{p0j}, b_{p0j}]$ ,  $|x_{0ji}| = |b_{0ji} - a_{0ji}|$ , and other symbols are the same as above.

### 3) Dependent Degree

Dependent degree  $K_j(P_0)$  of the evaluated object  $P_0$  and classification  $j$  is given below:

$$K_j(P_0) = \sum_{i=1}^n \alpha_i K_j(x_i)$$

Where  $\alpha_i$  is the weight value of characteristic  $i$  and

$$\sum_{i=1}^n \alpha_i = 1$$

### Determine the Classification

If  $K_j = \max \{ K_j(P_0) \}$ ,  $j=1, 2, \dots, m$ ,  $P_0$  is determined classification  $j^*$ .

Where  $m$  is the number of classifications.

### The Example of Application

#### Data of Evaluating Example

Monitoring data of water quality at the water intake of the Yellow River in Zhengzhou during 1997-1999 are given in table 1. The classifications, according to the water quality indicators monitoring the water quality parameters, are listed in table 2 [MEP, 2002].

TABLE 1 WATER QUALITY MONITORING DATA

Year	DO mg/L	COD mg/L	COD <sub>Mn</sub> mg/L	NO <sub>2</sub> -N mg/L	NH <sub>3</sub> -N mg/L	T-P mg/L
1997	8.14	25.4	4.84	0.211	1.581	0.064
1998	7.58	18.7	5.22	0.094	1.115	0.040
1999	8.6	30.2	4.78	0.125	1.345	0.065

TABLE 2 ENVIRONMENTAL QUALITY STANDARDS FOR SURFACE WATER (GB3838-2002)

Water parameter mg/L	I	II	III	IV	V
DO <sub>≥</sub>	7.5	6	5	3	2
COD <sub>≤</sub>	15	15	20	30	40
COD <sub>Mn</sub> ≤	2	4	6	10	15
NO <sub>2</sub> -N*≤	0.06	0.1	0.15	1.0	1.0
NH <sub>3</sub> -N≤	0.15	0.5	1.0	1.5	2.0
T-P≤	0.02	0.1	0.2	0.3	0.4

\* The classifications of NO<sub>2</sub>-N water parameter used GB3838-88.

## Results

Based on the above formula of matter-element model and the method to determine weights of evaluated parameters [Pan, et al, 2002], the dependent degrees of the evaluating object are listed in table 3.

TABLE 3 DEPENDENT DEGREES OF WATER ENVIRONMENTAL QUALITY OF THIS EXAMPLE

Year	I	II	III	IV	V
1997	-0.4588	-0.3994	-0.3096	-0.079	-0.1742
1998	-0.3010	-0.1507	0.0124	-0.1085	-0.4403
1999	-0.4487	-0.3895	-0.3373	-0.2591	-0.2712

Based on discriminating method of matter-element model, the water environmental quality of the water intake of the Yellow River during 1997-1999 is evaluated as IV, III and IV classification, respectively. If the method of fuzzy comprehensive assessment to evaluate this example and the same weights are utilized, the assessment results are the same as the matter-element model.

## Discussion

In the water quality standards, there is not upper limit of classification I for the DO parameter (table 2). In the matter-elements of  $R_{01}$  and  $R_p$ , determination  $b_{0j1}$  and  $b_{pj1}$  ( $j=1$ ) for DO are the effected objective factors (this example  $b_{011}$ ,  $b_{p01}=10$ ). So sensitivity analysis about  $b_{011}$  and  $b_{p01}$  is necessary. When  $b_{011}$ ,  $b_{p01}=9$  and 11, the dependent degrees for the water intake of the river during 1997-1999 are listed in table 4. The classifications of water environmental quality are labelled as IV, III and IV classification, respectively, the same as the case of the  $b_{011}$ ,  $b_{p01}=10$ , in which  $b_{011}$ ,  $b_{p01}$  are not sensitive for water quality evaluation in this example.

TABLE 4 DEPENDENT DEGREES UNDER SENSITIVITY ANALYSIS ABOUT  $b_{011}$  AND  $b_{p01}$

Year	$b_{011}, b_{p01}$	I	II	III	IV	V
1997	9	-0.441	-0.4172	-0.3282	-0.0954	-0.1869
	11	-0.4664	-0.3918	-0.2985	-0.0682	-0.1646
1998	9	-0.2825	-0.1537	-0.0066	-0.1271	-0.456
	11	-0.303	-0.1494	0.0238	-0.0961	-0.4285
1999	9	-0.4666	-0.4197	-0.3597	-0.2777	-0.285
	11	-0.4617	-0.3765	-0.324	-0.2468	-0.2609

Advantages of extension method for evaluation:

(1) Comparing with fuzzy comprehensive assessment, dependent function in matter-element model is fixed, and fails to establish fuzzy membership function affecting human factors. And the calculation of dependent function is simply, and has not maximum-

minimum operation, so it doesn't lose information.

(2) Comparing with grey cluster assessment, when upper boundary value or lower boundary value of classifications is the same (in table 2, the upper values of I and II classification for COD are the same), matter-element model is directly used and the limit value is not adjusted, so the affect of human factors is avoided.

(3) Dependent degree in the matter-element model may be negative value, so its distinguished ability is stronger, and can comprehensively analyze the degree of membership that evaluated object belongs to a classification. So this method can offer more information and make more accurate judgment.

Disadvantages of extension method for evaluation are:

(1) There is some uncertainty to build the matter-element matrix of classic domain.

(2) In evaluating problem, if there are qualitative indicators, the matter-element model can't be built directly. It is need to quantify qualitative indicators, then build the matter-element model and calculate dependent function.

(3) When all dependent degree values are negative, according to the comprehensive evaluation of the matter-element theory, classification of  $P_0$  is out off the classifications that have been divided [Cai, 1994]. This point is not suitable for the water quality assessment. In fact, the above recognition formula is suitably used for comprehensive evaluation problems.

## Conclusions

Based on briefly summary of the methods to assess the water environmental quality, this paper introduced the extension matter-element model, and demonstrated the evaluation procedure by the example. The evaluated result is same as fuzzy comprehensive evaluation, revealing that matter-element model applied to the assessment of the water environmental quality is feasible. Compared with the other comprehensive evaluation methods commonly used, this paper also summarized the characteristics and existing problems that the matter-element model has in the water environmental quality assessment.

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